Table 1. Heavy metals: background levels, annual loading rates and maximum cumulative loading rates.

Heavy Metal	*Background (ppm)**	*ALR (kg/ha/yr) †*	*CLR (kg/ha) ‡*
As	3–12**	2	41
Cd	0.1–1.0	1.9	39
Cr	1.5–40**	150	3000
Cu	1–50	75	1500
Pb	***	15	300
Ni	0.5–25	21	420
Se	0.1–3.9	5	100
Zn	9–50	140	2800

* Background levels are for eastern U.S., unless otherwise noted (N.Y. State Dept. Environmental Conservation 2001).
** These background levels are for New York only.
*** Background levels of lead vary widely. Average levels in undeveloped, rural areas may range from 4–61 ppm. Average background levels in metropolitan or suburban areas or near highways are much higher and typically range from 200–500 ppm.
† Annual loading rates (ALR) are from *Subpart B: Land Application*, which sets forth standards for application of biosolids on land, including surface spraying or spreading of biosolids, injection below the surface, or incorporation into soil for soil conditioning or crop fertilization. All values are on a dry weight basis (USEPA 1993).
‡ Cumulative loading rates (CLR) are maximum lifetime loading rates (USEPA 1993); kg/ha × 0.89 = lb/acre.

Table 2. Average heavy metal concentrations in N.C. soils (2003–05).*

Heavy Metal	*parts per million*
As	5.0
Cd	0.2
Cr	0.3
Cu	6.6
Pb	4.0
Ni	0.7
Se	0.2
Zn	18.7

* Based on NCDA&CS analysis (using Mehlich-3 extractant) of 5,776 soil samples from various sites where tests for heavy metals were requested

750 copies of this public document were printed at a cost of $130.56 or $0.17 per copy.

Agronomic Division

Heavy Metals in North Carolina Soils

Occurrence & Significance

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February 2003
revised October 2005

Steve Troxler, Commissioner of Agriculture

N.C. Department of Agriculture and Consumer Services

Soils normally contain low background levels of heavy metals. However, in areas where agricultural, industrial or municipal wastes are land-applied as fertilizer, concentrations may be much higher. Excessive levels of heavy metals can be hazardous to man, animals and plants.

By definition, a heavy metal has a specific gravity of about 5.0 or greater and is usually poisonous. The term *heavy metal*, however, is often broadly applied to include other potentially hazardous elements, even if they do not meet the strict chemical definition. The N.C. Department of Environment and Natural Resources regulates levels of the "heavy metals" arsenic (**As**), cadmium (**Cd**), chromium (**Cr**), lead (**Pb**), nickel (**Ni**) and selenium (**Se**) on waste application sites.

Agricultural, industrial and municipal wastes can only be applied to sites permitted by NCDENR. This process requires a soil test to establish baseline levels of the regulated heavy metals. Permit renewal requires additional testing—usually every five years and possibly at more frequent intervals—to assess heavy metal accumulation in the soil.

The N.C. Department of Agriculture and Consumer Services tests soils for heavy metals, according to NCDENR's regulations. For a fee of $25, it measures levels of **As**, **Cd**, **Cr**, **Pb**, **Ni** and **Se**. Two other heavy metals—copper (**Cu**) and zinc (**Zn**)—are measured at no charge by routine NCDA&CS soil tests since they are essential plant nutrients.

The U.S. Environmental Protection Agency has established annual and cumulative loading rates (maximum lifetime limits) for heavy metals (Table 1). NCDA&CS has compiled average heavy metal concentrations for land-application sites in North Carolina (Table 2).

Here is some useful information—natural occurrence, industrial uses, degree of hazard and likelihood of accumulation in the soil—for each heavy metal measured by NCDA&CS tests.

Arsenic (As)

Natural Occurrence: **As** occurs naturally in the mineral mispickel or arsenopyrite. Occasional deposits of elemental **As** are found, but for the most part, **As** is a by-product of the commercial treatment of ores of other metals. The U.S. is the largest commercial producer of **As**. All **As** compounds are poisonous.

Uses: Component in manufacture of bronze materials, fireworks, shot, agricultural chemicals, laser materials, glass, semiconductor materials, wood preservatives, copper and lead alloys and insecticides (most of which are obsolete)

Presence in Soil: In North Carolina, soils involved in waste applications contain an average of 5.0 ppm **As**, well within normal background levels of 3–12 ppm and far below the maximum cumulative loading rate of 41 kg/ha. In N.C., **As** content is insignificant in groundwater.

Cadmium (Cd)

Natural Occurrence: Greenockite is the only mineral of any consequence that contains **Cd**. Although **Cd** does occur in small quantities within zinc ores such as sphalerite, there are no notable occurrences of these minerals in North Carolina.

Uses: Component in manufacture of solder, electrical supplies, batteries, barriers to control nuclear fission, phosphors in the production of televisions, anticorrosive coatings for metals, bearing alloys, amalgam in dentistry and worm treatments for swine and poultry

Presence in Soil: Sewage sludge containing **Cd** and other heavy metals is frequently applied to agricultural land as a fertilizer material. In North Carolina, soils at these land-application sites contain an average of 0.2 ppm **Cd**. Normal background levels are 0.1–1.0 ppm.

Regular consumption of plants containing 3.0 ppm **Cd** can poison man and animals. It interferes with enzymes and other proteins. In livestock, it accumulates in the kidneys, spleen and liver.

In humans, **Cd** interferes with the metabolism of calcium and phosphorus, causing a painful bone disease. In southeast Asia, this disease has been traced to a diet of rice grown on paddy soils polluted with **Cd** from a mine source.

Chromium (Cr)

Natural Occurrence: Chromite, the principal ore, occurs in some mines in North Carolina.

Uses: Component in manufacture of steel, stainless steel, alloys, metal plating for prevention of corrosion, coloring agents for emerald green glass, chemical analysis, leather tanning, textile color pigments and mordants, and trace minerals essential to the nutrition of man and animals

Presence in Soil: In North Carolina, soils where waste has been land-applied contain an average of 0.3 ppm. Soil background levels of 1.5–40 ppm **Cr** are typical, and the maximum cumulative loading rate is 3000 kg/ha. **Cr** functions in mammalian glucose metabolism and appears to be essential to man and animals.

Lead (Pb)

Natural Occurrence: Rare in nature, **Pb** occurs in the minerals anglesite, cerrussite, minimis and galena. It is usually obtained from galena by a roasting process.

Uses: Component in manufacture of older paints, older plumbing hardware, ammunition, solder, metals, storage batteries, sound and vibration absorbers, lead gasoline, obsolete insecticides (lead arsenate), lead crystal and flint glass

Presence in Soil: In North Carolina, soils where waste has been land-applied contain an average of 4.0 ppm **Pb**. Soil background levels vary widely: as low as 4 ppm in rural areas or as high as 500 ppm in some urban areas. The maximum cumulative loading rate is 300 kg/ha.

Pb can cause health problems, particularly in children. It accumulates in the body and can build to toxic levels under continuous exposure. Concerns about **Pb** poisoning resulted in the elimination of **Pb** from gasoline, paint and plumbing lines.

Nickel (Ni)

Natural Occurrence: **Ni** is a constituent of most meteorites, and its presence is one of the criteria used for identifying them. Iron meteorites or siderites may contain from 5 to nearly 20 percent **Ni**. It is obtained commercially from pentlandite found in the Sudbury region of Ontario, which produces 30 percent of the world's supply.

Uses: Component in manufacture of stainless steel, other corrosion-resistant alloys, coins, nickel steel for armor plates, burglarproof vaults, vegetable oils, ceramics and greenish glass, Al-Ni-Co magnets and Ni-Cd batteries

Presence in Soil: In eastern U.S. soils, background levels of **Ni** typically range from 0.5–25 ppm, and the maximum cumulative loading rate is 420 kg/ha. In North Carolina, soils where waste has been land-applied contain an average of 0.7 ppm **Ni**.

Plants containing more than 100 ppm **Ni** develop symptoms of toxicity. Toxicity in grasses or other monocots closely resembles iron deficiency, exhibiting pale yellow stripes running the length of the leaf. In extreme cases, the entire plant may turn white with marginal necrosis (burn) of the leaf. In dicots, **Ni** toxicity causes an interveinal chlorosis (yellowing) that looks very similar to manganese deficiency.

Selenium (Se)

Natural Occurrence: Only a few rare minerals—crooksite and clausthalite—contain **Se**. It occurs in flue dusts remaining from the processing of copper sulfide ores. Today most of the world's **Se** comes from electrolytic copper refineries.

Uses: Essential nutrient in animal nutrition; component of dandruff shampoos and fungal infection treatments; used in manufacture of ruby-colored glasses and enamels, photoelectric cells, resistors, photographic emulsions, stainless steel, pigments, rubber, metal alloys, textiles, petroleum and medical therapeutic agents

Presence in Soil: Background levels in eastern U.S. soils are typically 0.1–3.9 ppm. In North Carolina, soils where waste has been applied contain an average of 0.2 ppm **Se**. The maximum cumulative loading rate for **Se** is 100 kg/ha.

Se benefits crop production and is essential to animal nutrition. A deficiency causes muscular dystrophy in livestock, known as "white muscle disease" and loss of hair. **Se** content in food and feed crops (for livestock) ranges from 0.1–1.0 ppm. Levels above 5 ppm cause "alkali disease" or "blind staggers." Too much **Se** also causes feather loss in poultry and malformation of livestock hooves and teeth. Although elemental **Se** is not toxic, compounds like hydrogen selenide are extremely toxic.

Se competes with sulfur in plant uptake. When toxic levels of **Se** are found in forage crops, addition of sulfur is a common remedial treatment. A sulfur rate of 15–25 lb/acre should be sufficient to reduce the toxic effect in animals. If **Se** levels are high, consult with an animal nutrition specialist and submit a forage sample for analysis.

Copper (Cu) & Zinc (Zn)

Natural Occurrence: **Cu** occurs in rocks, soil, water, air, plants and animals; **Zn** is a common element found in air, soil, water and all foods.

Uses: **Cu**—Component in metal alloys; electrical wiring; some water pipes; preservatives for wood, leather and fabrics; and some agricultural fungicides **Zn**—Widely used in industry to make dye, paint, rubber, wood preservatives and ointments

Presence in Soil: **Cu** and **Zn** are essential plant micronutrients. However, at high levels, they may be toxic to plants. They can also bind to soil organic matter and become unavailable to plants. Higher availability is usually associated with low pH.

Plants vary in their sensitivity to **Cu** and **Zn**. Based on field observation, critical toxic levels for plants that are not unusually sensitive are 60 ppm (NCDA&CS soil test Cu-I = 3000) and 120 ppm (NCDA&CS soil test Zn-I = 3000) for **Cu** and **Zn**, respectively. Peanuts are extremely sensitive to **Zn**, and toxicity has been seen at levels as low as 12 ppm (Zn-I = 300).

Nutrient management guidelines typically stipulate finding alternative waste application sites when soil levels reach 40 ppm **Cu** (Cu-I = 2000) or 80 ppm **Zn** (Zn-I = 2000), but where peanuts are grown, 20 ppm **Zn** (Zn-I = 500) is the limit. Waste applications should cease when levels reach the critical toxic level as noted above. Since **Cu** and **Zn** availability is highly dependent on soil pH, a pH of 6.0 should be maintained on mineral soils.

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